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ARTESIAN WELLS AND METHODS OF PUMPING THEM

BY JOHN D. KILPATRICK

NECESSITY FOR WATER SUPPLY FROM UNDERGROUND SOURCES

During the several years the speaker has been attending these conventions, he has observed that the papers and discussions on water supplies have been confined, in a great measure, to the treatment of water obtained from surface sources. These discussions have gone into considerable detail regarding the proper design and construction of filter plants, the design, construction and operation of filter beds, and a number of papers have been read on the proper method of still further destroying injurious bacteria which may have escaped elimination in the filter beds. But, there has not been much discussion on the subject of the design, construction and operation of water supplies obtained from underground sources, particularly those from driven wells.

In a great many localities the underlying formation is such that a water supply from a driven well system is impossible to obtain, but there are hundreds of municipalities where it is possible to obtain an artesian supply and consideration should be given to this source, even when a filtration plant is available.

A great point has been made in the discussions before this Association and also in reports of consulting engineers that artesian supplies are not permanent in character. The writer disputes this point, because his experience, extending over a great many years, has led him to believe that the fault is not with the underlying water bearing strata, but either with the construction of the wells themselves or to bad condition, due to neglect. It would be folly to generalize to the extent of saying that it is possible to draw an unlimited quantity of water from any given water bearing strata any more than the statement might be made that an unlimited quantity of water can be obtained from any surface stream, but there are many cases where the yield from the wells has steadily fallen off and where it was possible, by developing the wells and possibly changing the methods of pumping, to bring the wells back to their original and sometimes to an even greater yield. For example, the wells of Montgomery, Alabama, which gave some years ago about 5,000,000 gallons of water per day had dropped off until it was possible to obtain only 4,000,000 gallons per day. By cleaning out the strainers and developing the wells, and by this latter term is meant cleaning out the fine sand which had collected in the region surrounding the strainers, and installing a more efficient type of air-lift, these wells were brought up to yield approximately 5,500,000 gallons per day. This was in a sand formation. A number of similar instances could be cited, but lack of time will not permit. The writer refers particularly to wells driven through sand or gravel formation where the use of a strainer is necessary. Of course, in the case of wells driven into the rock, it is only possible to obtain from any rock hole the amount of water contained or flowing through the crevices and fissures in the rock. With sand holes, however, the yield from any well is greatly affected by methods of construction and development of the well when drilled. The writer has drilled wells that yielded 15 gallons per minute which have been brought up to over 300 gallons per minute before being put into service.

In locations where there is a choice between artesian well water and a surface water supply that has to be filtered before it is possible for the water to be used, more consideration should be given to an artesian supply if the cost of the plant and the cost of water delivered to the pressure pumps is close enough to allow of debate. This opinion is based solely on the ground of the purity of the supply. After hearing the many interesting papers that have been read at these conventions on the subject of filtration for large municipal supplies, the writer realizes that there is a tremendous field for filtration and that it has solved the problem of water supply for a great many cities in this country and abroad; and further that for the larger cities in this country an artesian supply which has to be pumped to the surface of the ground is, in a great many cases, entirely out of the question.

The writer refers particularly to the purity of supplies from driven wells and admits at the same time that driven well water in almost every case is harder water than that obtained from surface streams. In very few cases, however, does driven well water have to be treated either to clarify or purify it. The installation of a filter plant for the clarification of a surface supply is not the end of that problem; ceaseless vigilance in the care of the filter is the only price of safety.

There are localities where it is debatable whether an artesian supply is better and more economical to operate than a supply taken from a surface stream that is to be filtered, and still other localities where there are no surface streams and the municipality is compelled to resort to artesian wells.

The problems involved in the laying out of an artesian well system may be grouped under three heads:

1. Location of the wells.
2. Methods of drilling and construction.
3. Methods of pumping.

No consideration will be given in this paper to the methods of pumping from the pump house up to the storage reservoir, nor to distribution systems. Only the delivery of the water to the suction basin in connection with the main pumps will be treated.

LOCATION OF THE WELLS

The location of the wells depends upon the extent and surface conditions of the land available for the well field. No rules can be set down for the proper location of wells until test wells have been drilled, unless the underlying conditions are known from wells in the vicinity. In laying out a pumping plant which will obtain the supply from wells, as a general rule, it is best to drill the wells and locate the pump on the lowest possible ground available. The obvious reason for this is that in drilling the wells we penetrate to the underground stream and the object is to have the pumped level of the water as close to the surface as possible, because as a general rule it is more expensive per foot of pump head to deliver the water to the surface of the ground than from the surface reservoir up to the storage tank. If the well field is to be in a well defined valley, it is preferable to drill the wells in a line across rather than parallel with the direction of the valley, because the underground stream of water may flow in the same general direction as the surface streams. This, however, is not always the case, and before locating definitely any number of wells, it is advisable to drill test wells at various points. There have been cases where city councils have taken the matter into their own hands and have drilled wells on the summit of the hill on which they have decided to place the storage reservoir under the specious reasoning that if they could get a flowing well in the valley, they should get on top of the hill a flowing well delivering its water freely into the storage reservoir, which would save the expense of pumping. Unfortunately, water will not rise above its source and the money spent on drilling these altitudinous wells has been thrown away. There are places where it is possible to obtain flowing wells on the summits of high hills, but they are the exceptions which merely prove the rule.

In regard to the location of underground water supplies by the use of forked sticks, magnetic balls, pendulums, indicators for radio activity and other devices, the belief in such occult means is only evidence of the survival of a superstition of the alchemist's age. The writer has known some of the most famous of these so-called "dousers," but has never yet been able to pin them down to statements which they were willing to back up by a bond.

This afternoon the speaker went out into the country and cut a couple of forked sticks; whether these forked sticks are from peach trees, witch-hazel bushes or not, is immaterial. Placing this glass of water on the floor you will note that when one branch of the fork is grasped with the right hand and the other with the left, in walking over the glass of water the stem of the fork dips. You note that the dip takes place. Now, walking down the aisle you note that the stick dips again, showing that the presence of water has nothing whatever to do with the curious action of the stem of the twig. The explanation of this phenomenon is that it is only possible to operate a forked stick when the hands are held palms up. This position brings the little fingers of each hand on the inside. You will note after holding your hands with palms up, your fists tight together and gripping hard, that within a few seconds you will feel a strain on the muscles of the forearm which can be instantly relieved by releasing the grip of the little finger a trifle and possibly the third finger also. If you are holding the forks of a twig in your hands the release of the grip by the little finger and the third finger, together with an almost imperceptible turning of the fist downwards and inwards, will cause the stem of the twig to dip. This, accompanied by a releasing of the tension on the pro nator muscle that extends from the thumb side of the wrist diagonally across the forearm to the inside of the elbow, when the hands are held palms up, is the explanation of the dip. The mysterious action of the twig, therefore, is not influenced in any way by the action of subterranean water, but is due either to unconscious reflex action on the part of the operator, or is caused by "malice aforethought" on the part of the same worthy when he thinks he is in the neighborhood of a favorable spot for the location of a well. The reason for the continued vogue of the uncanny action of the divining rod in the hands of these self-styled "water-finders" is due to the fact that the average citizen has a sneaking fondness for the occult; and when a "water-finder" makes good on the location of a well, the fact is advertised far and wide, and when he falls down, his failure is expected as a matter of course and is soon forgotten.

There have been a number of other methods used by "water-finders" that have come under the speaker's observation in the last twenty years. One of them, a Russian, had a mysterious box from which was suspended a pendulum. He would start this pendulum oscillating east and west and walk over a tract of land; and he claimed such mysterious power for himself and the pendulum that when he was vertically over the underground stream, the pendulum would stop oscillating east and west and swing in a northerly and southerly direction. At that point he would drive a stake; then he would start at the edge of the property again, a few yards further off, and walk in a parallel direction to his first line until the same change in the pendulum took place and then he would drive another stake. In this way he would plot out the direction of an underground stream. The violence with which the change in the swing of the pendulum took place would give him an idea of the depth. This scheme was all right and the Russian made a great many thousands of dollars out of it. No one, however, ever saw the box or the pendulum, which he concealed under a long and wide coat which he always wore. His compensation was based upon his demanding a fee of $100 for making what he called a "survey," and then getting a fee of $500 if his predictions came true. The old man generally arranged to go to the neighborhood of the tract two or three days before his formal survey and gather all the information he could about wells in the vicinity, and by taking differences in the level of the ground, he sometimes made very close guesses, and, as remarked before, you only heard about his successful surveys and never about his failures.

Another famous "douser" in New York asserted that he could feel the underground water in the ends of his fingers if he walked over the suspected territory with his arms outstretched. There was another one who had a box containing mysterious electric indicators by which he registered the radio activity of the underground water. This radio activity of the underground water acted in an opposite direction to the force of gravity and passed through concrete cellars, flooring, the roofing and all other materials, so that it was just as easy for him to discover underground water from the roof of a ten story building, as it would be in the cellar of the same building. This man "got away with it" for three or four years, because, as we all know, there is one gullible person born every minute.

The only scientific method of determining the location for a well is to obtain all the information possible about wells in the vicinity together with all possible data regarding the underlying geological formations. A combination of experience with the aforesaid data and information is of considerable value. In addition to this information, test wells should be drilled to the maximum depth considered necessary and should not be less than 6 inches in diameter so that a pump of reasonable size can be installed and some conclusion drawn from the yield of the "prospect well." After these "prospect wells," the number of which will depend upon the local conditions, have been drilled and tested, sufficient data is at hand upon which to estimate the total number of wells that will have to be drilled to give the required yield. Great care must be taken to obtain an accurate record of all the formations passed through and frequent tests must be made to determine the yield at different depths.

METHODS OF DRILLING AND CONSTRUCTION

Driven wells may be roughly divided into two classes: (1) those where the water supply is obtained from the rock, and (2) those where the water bearing strata lie above the rock. A third class might be added, a combination of these two.

1. Where the rock lies at a short distance below the surface of the ground and the quality of the water above the rock is unsatisfactory, the pipe should be driven so as to seat firmly into the rock, shutting off the surface water. The most satisfactory method of doing this work in the case of the 8-inch finished hole in the rock, is to drive a 10-inch pipe down to the rock and drill a 10-inch hole in the rock far enough to be surely into the solid rock and below the shattered and seamy top surface. An 8-inch pipe should then be lowered to seat into the bottom of the 10-inch hole in the rock and cement grout poured in sufficiently to fill up the annular space around the 8-inch pipe in the 10-inch hole in the rock. After this is set and the 8-inch hole drilled on in the rock, the 10-inch pipe may be withdrawn for use in another well.

During the drilling of the well, tests should be made by means of sand bucket or working barrel to determine the yield at different depths. A good indication of passing through water bearing crevices is the rise or fall of the standing water in the well. If continued drilling shows the same character of rock and the standing water level remains the same, it is a good indication that there is no great change in the possible yield of the well. Another indication of very little water in a rock well is shown by a great rise in the water level in the well when the drilling tools are lowered. When the well has reached the required depth, a test should be made, either with the working barrel, or the air-lift. If there are a number of wells to be put in, and the air-lift system is to be adopted for the permanent pumping plant, and the test is made with a working barrel, it is advisable to place the working barrel at a point below the surface so as to leave sufficient depth for the submergence of the air-lift. For instance, if the wells are 200 feet in depth, the writer would not recommend that the working barrel be placed more than 100 feet below the surface of the ground and the yield determined at this point.

2. The construction of wells in sand or gravel. In driving wells through sand or gravel, it is essential that the drive pipe be of strictly wrought iron and equipped with patent recessed couplings, and care must be taken so that the ends of the pipe butt in the couplings and that the pipe be shod on the lower or cutting edge with a steel drive shoe. The reason for the pipe butting in the couplings is to carry the effect of the blow of the tools directly through the pipe to the drive shoe instead of having the impact come upon the threads in the couplings.

The proper strainer and the placing of it is the next point to be considered. If the strainer is to be placed at the bottom of the well, this may be done either by driving the pipe through the water bearing strata, introducing the strainer, and jacking back the drive pipe so as to uncover it; or the drive pipe may only go to the top of the water bearing sand and the strainer pumped or driven into proper position. In the first case the strainer may be plugged before being lowered, but chances would be taken in the ability of the well driller to jack back the drive pipe. In the latter case, difficulty is sometimes found in placing the plug securely. In either method of construction, it is essential that means be taken to prevent sand from running up alongside the strainer between the top of the strainer and the well casing. This sand is kept out either by putting in a lead packer or by continuing an extra line of pipe from the strainer up to the surface of the ground. Where the lead packer is used, the strainer is lowered into the hole, and in order to withdraw it any time, considerable difficulty is usually found in getting hold of it and getting it out of the well without destroying the strainer. As a general rule, it is better to lower the strainer into place by means of piping extending all the way to the surface of the ground and then, if it is necessary at any future time to withdraw the strainer, it is a comparatively simple matter to do so. In case the water is found in three or four strata with some distance between them, it is necessary to drive the pipe to the extreme depth and then lower the strainers into place with the proper connecting pipes between them, and then jack out the well casing at least as far as the top of the uppermost strainer.

The operation of jacking back pipe is one involving risk on account of the pipe parting under the strain. The only precautions that can be taken are to sand pump freely and frequently when the pipe is being driven, have the strainers on the ground and lose no time in placing the strainers before jacking back the pipe, so that the sand and gravel will have as little time as possible to pack around the drive pipe couplings. Cutting the drive pipe may be resorted to in case it is unnecessary to withdraw the lower part of the drive pipe, which may have been driven to give the necessary amount of submergence in the case of an air-lift well. The necessity of insisting upon the pipe being butted in the coupling is observed more particularly when jacking operations are required, because if the pipe is not butted there is even greater danger of stripping the threads. In case a pipe parts when being jacked back, it may result in a lost well.

3. Under the third heading, where water may be obtained from the formations above the rock and from crevices in the rock, the construction of the well differs in no way from those referred to in the first two actions.

METHODS OF PUMPING

The pumping of driven wells may be done either by suction, deep well pumps, rotary or screw pumps, or the air-lift. In case the water rises high enough in the wells to be pumped by suction, it is unnecessary to speak of this other than to say that method of pumping is familiar to anyone who has ever done any hydraulic work. The only prime necessity for a successful suction plant is tight suction lines, and good foot valves.

In regard to deep well pumps, these may be used when only limited supplies are required and where the water does not rise in the well high enough to make an air-lift economical. The question of whether to use single acting well heads with single acting barrel, or single rods with double acting barrel or double rod heads with double plungers depends entirely upon conditions. Except under extreme conditions, the speaker does not believe it advisable to use deep well pumps where there are more than two wells on account of the spacing between the wells and the necessity of building separate pump houses over each well and for other obvious reasons of economical pumping.

For any number of wells scattered as they usually must be over quite an area, the air-lift system has proven itself to be the most available method for delivering a large supply of water on the surface of the ground. It is not advisable, however, to use the air-lift except under extraordinary conditions for delivering the water higher than to the level of the ground. At best the air-lift is an expensive way of pumping, but where the water is obtained in large volume below suction limits, it would seem to be the only possible method. The air-lift system has the great advantage of not having any moving parts in the well, and there is absolutely nothing to get out of order in the air-lift itself. The moving parts of the system are all in the air compressor in the engine room, under the eye of the engineer. The engine room may be located at the most convenient point, taking into consideration the supply of fuel, and the furthest well may be a mile or more away from the air compressor. If the air lines are correctly designed and properly buried, there need be but little loss of pressure. The main fault that the speaker has found with a great many air-lifts throughout the country has been in the air-lift piping in the wells. It is a familiar fact that a prime consideration for an economical air-lift is that there should be 60 per cent submergence. For instance, in a 100-foot well, there should be at least 60 feet of water when the well is delivering its yield; but the principal trouble is found in the design of the air and water piping, so that the compressed air is delivered at the bottom of the uptake water pipe with as little loss by friction as possible, and that the uptake water pipe is designed so as to deliver the water, without being so large as to have an extreme amount of slip or so small as to develop excessive friction. Evidence of faulty design is shown by the discharge being in alternate pistons of water and air. In a properly designed air-lift system, the water should be discharged in a practically uniform stream, with very little surging. A great many foot-pieces have been designed which have for their object the spraying of the air at the bottom of the uptake water pipe so as to introduce the air into the water in streams of very fine bubbles. It was discovered early in the development of the air-lift that the finer the spray could be made, other things being equal, the more efficient the air-lift became; but no foot-piece that was ever designed can work efficiently if the air pipe leading down to it and the uptake water pipe from it are not of such sizes as are suitable for the particular problem involved in that well. The great object to be accomplished by any foot-piece is to offer as free and clear a water passage as is possible so that there will be no eddies formed in the water column which cut down the velocity and impair the efficiency. Above the foot-piece the mixture of air and water should have a pipe with as smooth surfaces as it is possible to obtain.

The three methods of piping wells may be termed: (1) the outside air pipe; (2) the inside air pipe; (3) the annular system. In the first case the air passes down outside the water pipe and into some type of foot-piece or openings at the bottom with the water passing up through the inside of the water pipe. In the interior pipe system the air passes down the inside air pipe to a foot-piece or nozzle, and the mixture of air and water is blown upward between the outside of the air pipe and the inside of the water pipe. In the annular pipe system, one pipe is within the other, the space between the two pipes being the downtake air column, and the interior of the inside pipe being the uptake water discharge pipe. It is impossible, without an exact knowledge of the conditions, to determine which of these three systems it is best to use, assuming that the proper areas are available in each case for the amount of air necessary and the amount of water required to be lifted. There are cases where the diameter of the well is so small and the amount of water to be delivered so large that there would not be room in the well for the outside air pipe, in addition to the uptake water pipe. In this case, it might be better to use the well casing as the downtake air pipe and only provide an uptake water pipe. This arrangement, however, is sometimes impossible on account of air leakage through the joints of the well casing, which were opened up when the well pipe was driven. It is very hard to generalize and lay down rules for piping up wells on account of the different yields, depths and submergence of wells, and this is sometimes still further complicated by the number of wells that have to be pumped. With a great number of wells to be pumped from the same air compressor, very delicate adjustments are required so that all the wells may be started at the same time. The speaker believes that it is preferable to use a single air line, with outlets to each of the wells, rather than separate air lines from the pump house to each of the wells, both as a matter of economy of installation and economy in the use of air. The plea sometimes made that independent air lines to each well allow of adjustment within the engine room is valid because the place to adjust the well is at the well itself, and if the plant is properly designed originally, it should not be necessary to adjust the wells except at considerable intervals of time, and then only because of the increased requirements made on the plant, or fluctuations in the wells themselves.

Another rule, the observance of which should be insisted upon, is that the air-lift should only be used to deliver the water high enough above the ground to allow of a flow to a surface suction basin close by the force pumps.

The writer has not referred to air pressure machinery, but considerable economies can be made in this part of an air-lift system by installing compound and condensing machines and by 2-stage air ends. The great loss of economy in the ordinary air-lift system, however, is not in the engine room but in the air-lift pump in the wells. Insufficient submergence, caused by pumping too great a quantity from a well, and thereby lowering the head to a point where the increase in the amount of air necessary is out of all proportion to the quantity of water obtained, or by the use of piping either too large or too small. No foot-piece ever designed will do the impossible, but a properly designed foot-piece in connection with correctly designed air and water pipes will make the air-lift an important factor in the pumping of deep wells, and a properly designed air-lift system in connection with wells that have a good flow of water will result in pumping costs which will compare favorably with the cost of some surface water supplies that have to be filtered.

DISCUSSION

Mr. Chester R. McFarland: What do you find to be the most efficient velocity of the water rising in the pipes?

Mr. J. D. Kilpatrick: The most efficient velocity depends upon the air pressure, the size of the pipe and the depth of submergence. The velocity should be so low that the friction in the uptake pipe is negligible.

A Member: What is the highest efficient velocity which you can get?

Mr. J. D. Kilpatrick: As stated before, this depends upon the pressure. The speaker has never made any experiments to determine the velocity in feet per second of the discharge of the air-lift well, but in accordance with common practice, has made calculations in gallons of water discharged per square inch to the area of the uptake water pipe. In a deep well with high air pressure the speaker has discharged as high as 29.5 gallons per square inch, and recently, in New Jersey, was able to obtain a discharge of 31 gallons per square inch. With shallow wells, and consequently lower air pressure, the usual discharge is from 12 to 15 gallons per square inch.

Mr. Chester R. McFarland: The water had to travel the whole length of the pipe or you would not have had a discharge.

Mr. J. D. Kilpatrick: That is true. The velocity is a question of simply dividing the area of the pipe by the amount of water discharged per minute to get the velocity.

Mr. Chester R. McFarland: In an experience extending over a period of about twenty years, the speaker has been led to believe that each individual case must be treated according to the conditions as they are found, and that a deep well with a very great submergence and high lift will require a greater velocity than the one of much less depth, to secure the highest efficiency of the work done by the compressor. This being the case, for the same quantity of water delivered from a deep well the area of the water pipe should be much less than that in a shallow well.

MR. J. D. KILPATRICK: The government specifications issued by the quartermaster's department of the United States Army seem to be based upon the wrong conception of the operation of the air-lift. These specifications call for double, extra heavy pipe on the top, extra heavy pipe for the middle lengths, and standard pipe for the lowest lengths. Piping the well up in this manner means that the area is smaller at the top than it is at the bottom. The arrangement of the pipe should be reversed, that is, the smallest diameter should be at the bottom, and the largest diameter at the top. The reason for this is that the compressed air which is jetted into the water at the bottom is at its maximum pressure, and the bubbles are consequently smallest. As they travel upwards in the discharge pipe, they expand, and the pressure becomes less, with the result that more area is necessary at the top of the water discharge pipe than at the bottom, on account of the greater space occupied by the expanding bubbles of air, the quantity of water being the same at the bottom as at the top.

A MEMBER: What do you do when you have a rock only about 150 feet down?

MR. J. D. KILPATRICK: Let us suppose that we drive a 10-inch pipe above the rock, and desire an 8-inch hole in the rock. The operation would consist in driving a 10-inch pipe down to the rock, and the well driller will then continue with his 10-inch bit and make a 10-inch hole in the rock far enough to pass through the seamy top surface of the rock. An 8-inch pipe, with ordinary couplings and full lengths, is lowered with a coupling on the bottom of the lowest piece. This 8-inch pipe is lowered into the 10-inch hole, and the coupling on the bottom firmly set on the bottom of the 10-inch hole in the rock. The space between the outside of the 8-inch pipe and the inside of the 10-inch hole in the rock is filled with liquid cement grout up to the top of the rock. The well driller then proceeds to drill the 8-inch hole in the rock as far as necessary, and at some convenient time pulls out the 10-inch pipe which was driven from the surface of the ground down to the rock; the reason for withdrawing the 10-inch pipe is that there is no necessity for it, and it is available for use in another hole.

Several members have asked regarding the advantages of blasting or shooting a rock well. The answer would be that shooting a well is resorted to in the oil regions to break up the oil-bearing sand, when this has been encountered. In shooting a well for water supply, a greater flow can sometimes be obtained if you are absolutely sure where the water bearing fissure in the rock has been encountered. The trouble with most well builders is that they cannot determine this exact point, and it may be that the shot is set at the wrong place, and may result in the closing up of the water bearing fissure instead of enlarging it. As a general rule the speaker does not believe that blasting a well is a sure way of increasing the water supply from that well, but at the same time there are a number of cases in which it has proven very successful.

MR. JOHN W. MOORE (by letter): The writer has had a wide experience in designing and remodeling air-lift pumping systems and the question the gentleman has raised as to the proper speed of the air and water in the eduction pipe is of very great importance. When this most advantageous speed has been determined for all conditions the writer suggests that with the information now at hand the average consulting engineer will be able to design successful air-lift pumping systems of the highest efficiency.

It is apparent that a constant velocity is neither desirable nor possible; therefore it would follow that the best that could be done would be to ascertain the maximum and minimum permissible velocity at both the lower and upper end of the eduction pipe, the velocity at the intermediate points to be governed by the diameter of pipe available and possible to install in the well.

The writer after running tests on many air-lift pumping plants of his own and other designs has decided on what he believes to be the most advantageous velocity of the air and water in the eduction pipe for lifts of from 30 feet to 175 feet.

If observations of plants the writer now has under construction should verify the information secured during the last four years, the writer will be pleased to lay such information before those of this Association who may be interested.

MR. M. N. BAKER: The speaker well remembers the water-finders, Hartdegen and Schnee. He had come to New York a few years before, and it was his duty to accompany those gentleman on several expeditions. On one of these we had some large hose with water running through it stretched around on the floor of a large vacant building. We took Messrs. Hartdegen and Schnee up on the floor above and had them chalk out their indication of the stream of water. It is hardly necessary to say that they did not come anywhere near it. Of the many who witnessed their demonstration one man was a member of the American Society of Civil Engineers and another has since been a prominent official of the American Institute of Mining Engineers.

A few years ago the government auditor of municipal accounts refused to audit a bill that a British town council had incurred for water finding, and the members of the town council had to meet the bill out of their own pockets.

Hartdegen and Schnee shrouded their water-finder in mystery. Waterfinders of a later and the present day claim to use "electrical" instruments and put forth clever but blind explanations as to how they operate.

In 1910 some enterprising water-finder succeeded in interesting the Agricultural Department of India to make an investigation of his device. The department published an interesting little pamphlet purporting to show that the water-finder investigated was a good thing. That pamphlet has recently been circulated in this country by some one giving his address as Providence or Pawtucket, Rhode Island.

Mr. Wirt J. Wills: The speaker simply wants to rise to thank Mr. Kilpatrick for having introduced a subject that is very near and dear to him. The speaker has been a member of the American Water Works Association for ten years, and with the exception of one engineer making a feeble attempt to say something about ground waters, this is about the first time that anything has been mentioned in regard to pumping from deep wells, or at least anything in an exhaustive way. Representing presumably the largest artesian water plant in the world, all that the author of the paper said was very interesting to the speaker, who does not desire to make a talk on this subject, except to say that we have three systems in Memphis, all very successful. One invented by the speaker, the name of which he will not mention because it is not on the market, consists of fifteen one million gallon pumps, stretching over a distance of ten miles. During the drought, last summer, the longest dry season ever known in that country, our mayor published a card in the paper advising everybody to use all the water they wanted, but we kept up with the demand right along.

With thanks to Mr. Kilpatrick for introducing this subject, the speaker hopes in future meetings we will have more discussion on this topic.

Mr. Oscar Bulkeley: The speaker would like to ask Mr. Kilpatrick if he has found a good method of drilling a well so as to be sure of securing a straight bore. Of course it makes no difference if one intends to pump with air, but it makes a very vital difference if any other type of pumping equipment should be used. Perhaps the rotary method of drilling is the most successful, but the speaker wonders if Mr. Kilpatrick can furnish any information on this subject.

Mr. J. D. Kilpatrick: In driving a pipe it must be remembered that the direction of the hole is entirely dependent upon the threading of the casing. The well driller sets his first length of pipe as near vertical as he can, drives this to its depth, screws on another length, drills that, and sand pumps and drives till he is ready for the other length, etc. The straightness of the hole depends upon the care with which the pipe company has threaded the pipe. The reason that so many well drillers get a crooked hole in the rock is that they drill with a slack cable. The well driller will usually get a straight hole if he drills on the spring of the cable, that is, with the tools hanging free in the hole, the distance off the bottom depending entirely upon the length of drill cable. In drilling with a taut cable the tools hit with a sharp blow, which is caused by the fact that the up stroke of the walking beam corresponds with the stretch of the cable. In drilling with a slack cable the tools do not hang free and clear in the hole, and the length of the stroke is cut down considerably. It is a very difficult job to drill a straight hole even with the best of care, if the rock is in layers of very hard and very soft material lying almost vertically. In this case the tools will be sure to work over into the soft material and make a crooked hole, in spite of all precautions. Sometimes a guide can be put on the stem, but in an experience once in Mexico every method known at that time failed, and we were forced to drill with a rotary drill.

Mr. A. A. Reimer: The method outlined by Mr. Kilpatrick for obtaining a pipe joint in passing from soil to rock is of course a perfectly sure method; but oftentimes in fairly soft rock you can save that expense if you have a good iron shoe. A well dressed shoe, you can drive into rock with a little care in keeping the tools going pretty close to the shoe all the time. The edge of the tool will cut say three-quarters of an inch of rock under the drive of the machine, so that you can actually drive your pipe right into the rock, perhaps 3, 4 or 5 feet. In some cases that is all that you need for cutting—a good drive. That is all you need in that character of rock; but in hard rock the other method, of course, is necessary.

Mr. J. P. Berry: We have four deep wells in our city, each being approximately 1378 feet deep, and we have had no trouble in drilling them straight. Three of the wells are 15 inches down to a depth of 100 feet and from there to the bottom they are 8 inches in diameter. One well is 20 inches to a depth of 200 feet and from there to the bottom 12 inches. These wells are pumped with centrifugal pumps. An agreement with the contractor was, that he must put down a dummy pump, the size of the pump to be used in the wells, to a depth of 200 feet and this dummy pump must pass in and out freely before any payments were made. This was to show that the hole was perfectly straight and that the pump could be inserted and taken out when needed.

These wells are pumped at the rate of 1,000,000 gallons per day. Two of these pumps are electrically driven with direct connected motors. One pump is electrically driven with a belt drive and one pump is operated by steam. These pumps have worked very satisfactorily with us. Electricity is purchased from a private company at a cost of 0.02 per kw. It costs about 0.01½ per 1000 gallons to put the water in the reservoir.

Mr. Oscar Bulkeley: The question of straightness is something that is of great importance; more than many realize. The speaker believes that there are a great many well men who have heard about straight holes, but have not got them. If we were to make a test of them we would find that they are crooked. There is a great deal of misrepresentation in regard to drilling a well straight. Contractors will say that they will drill a straight well, but they do not always do it.

Mr. Edward S. Cole: Will Mr. Berry kindly tell us how his vertical shaft and pump are lubricated.

Mr. J. P. Berry: The shaft goes down inside of a 3-inch casing, and the lubrication goes down inside of that. There is no water around the shaft. The shaft goes from the motor connection straight through. One pump ran 18 months without missing a day. Some Sundays it was shut down for an hour or two, but it ran the whole 18 months practically night and day, delivering 700 gallons a minute. Then it was taken out. It has been very economical.

Mr. Wirt J. Wills: To find out whether a well is straight, if you have a contractor who cannot tell you, make him take a looking-glass and by looking down with that you can tell if it is not overflowing.

Mr. Francis D. West: This has been an important and interesting subject and the speaker is glad to see that the fact has been emphasized that the air-lift is a very good means of pumping deep wells.